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EVALUATION OF SONAR RANGING MEASUREMENTS OF RIVER WATER LEVELS

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by

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ABSTRACT

This report describes the characteristics of a sonar ranging system developed by the Alberta Research Council to measure water levels on large rivers. The system is composed of two primary units: the sonar transceiver unit, which uses the Polariod Environmental Ultrasonic Transducer and the Texas Instruments Sonar Ranging Module and the sonar control unit, which has been designed to control the system and interface with a pulse counting data logger in one variation and in another an analog data logger.

The unit functions over the whole range of environmental conditions found in Alberta and can measure distance from between 0.6 m and 15 m with an accuracy of ± 4 mm, if temperature compensation can be made. The system was verified against WSC stage measurements on the North Saskatchewan River and overall it was found to represent water levels to be within ± 0.10 m of the WSC measurements. Most of this error was a result of not adequately defining the characteristic temperature of the air column. When this was done, the errors were reduced to ± 0.04 m. In all likelihood the sonar system out performed the WSC system, given the latter's propensity for variable clock speed and poor resolution of the strip charts.

With more accurate measurements of the air temperature the sonar system should prove to be a valuable tool, useful for accurately measuring river water levels under a variety of normal and severe conditions.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

1.1 Background

Most common water level measurements currently are being made by a variety of types of instruments. These range from simple floats positioned in a stilling well to more complex nitrogen bubbler gauges or pezioresistive pressure transducers. Regardless of the types of instrumentation, the float or the probe must be in contract with the water to sense the level or hydrostatic pressure of the body of water being measured.

These restriction causes numerous difficulties during severe flood conditions or during freeze-up or breakup. During major flood events the orifice to the stilling well can siltin or the stilling well can be overtopped. This results in a loss of record. In the case of the pressure transducer or the nitrogen bubbler, the orifice can be moved, hence giving inaccurate stage measurements. During freeze-up or break-up the orifice is often damaged, moved, or the line connecting the orifice to the gauge is cut by the action of the ice. In cold regions this latter problem often results in a loss of records during the time when the annual water level peak is produced.

In many cases the perceived accuracy of the above water level measurement techniques is not required, especially at a cost of frequently losing valuable data. Instead, there is a need to develop a rugged method to measure water levels under a variety of severe conditions, even with some loss in accuracy.

Significant advances in the development of sonar ranging devises have been made with the introduction of the auto-focussing cameras. These advances now make it possible to use sonar ranging as an alternative method of measuring water levels. Reasonable accuracy can be achieved if some enhancement of the raw data can be made to allow for the variation of the speed of sound in the air column between the sonar ranger and the water surface. With the development of Canada's

transportation systems, bridge crossings have been constructed over many rivers at numerous locations. These provide suitable structures on which to mount sonar ranging systems. This removes the necessity for near-bank measurements which complicate the downward ranging process during ice runs.

One such sonar ranging system has been designed, constructed and tested by the Alberta Research Council (ARC). Testing was undertaken on the Low Level Bridge over the North Saskatchewan River at Edmonton. This is the location of the Water Survey of Canada (WSC) gauge #05DF001. The field trial was undertaken in a period of time before break-up, during the formation of the ice cover, and for a period of time during the existence of a stable ice cover.

1.2 Objectives

This report describes the principles of sonar ranging and the ARC system which was developed to measure water levels. A description of the interfacing of this system to commercially available logging devises is also given.

The main objective, addressed herein, is to evaluate the performance of the system under relatively severe environmental conditions. The data generated by the ARC system is compared to the best available WSC estimates of the water levels. Recommendations with respect to the usefulness of the ultrasonic system are made along with suggested improvements to the prototype.

2.0 THE SONAR RANGING SYSTEM

The sonar ranging system is composed of four units: the sonar transceiver unit, which supports the sonar transducer; the sonar control unit, which acts as an interface between the transceiver and the logging device; a logging device such as the Lakewood LE8100 or Campbell Scientific 21 X, and a thermocouple which measures air temperature and is used to compensate for the effects of air temperature on the velocity of sound.

Figure 1 is a schematic of the system showing the connections between the sonar transceiver, the control unit, and the data logger (not shown). For use with the Lakewood logger, a digital to analog converter is required and has been developed along with a digitizing control unit. The Campbell logger has a high speed pulse counter, consequently this conversion feature is not required, thus substantially simplifying the system.

2.1 Sonar Transceiver Unit

The sonar transceiver unit is composed a sensor, the Polaroid IP44494 Environmental Ultrasonic Transducer (EUT) and a driver, the Texas Instruments SN 28827 Sonar Ranging Module (SRM). A schematic is shown in figure 2. The transducer acts as both a transmitter and receiver. Its main moving part is a piece of thin gold plated plastic foil stretched over an aluminum backplate (figure 3). This foil transforms electrical energy into sound waves and conversely, sound waves into electrical energy. A steel spring which also is used to maintain a constant tension in the foil is used to transfer voltage from the backplate. A perforated front cover mechanically protects the foil with only a small loss of signal strength.

The backplate and the foil represent an electrical capacitor, which when charged causes an electrical force to be exerted on the foil. An AC voltage of a given frequency forces the foil to move at that same frequency and thus to emit sound waves. A DC bias voltage is applied

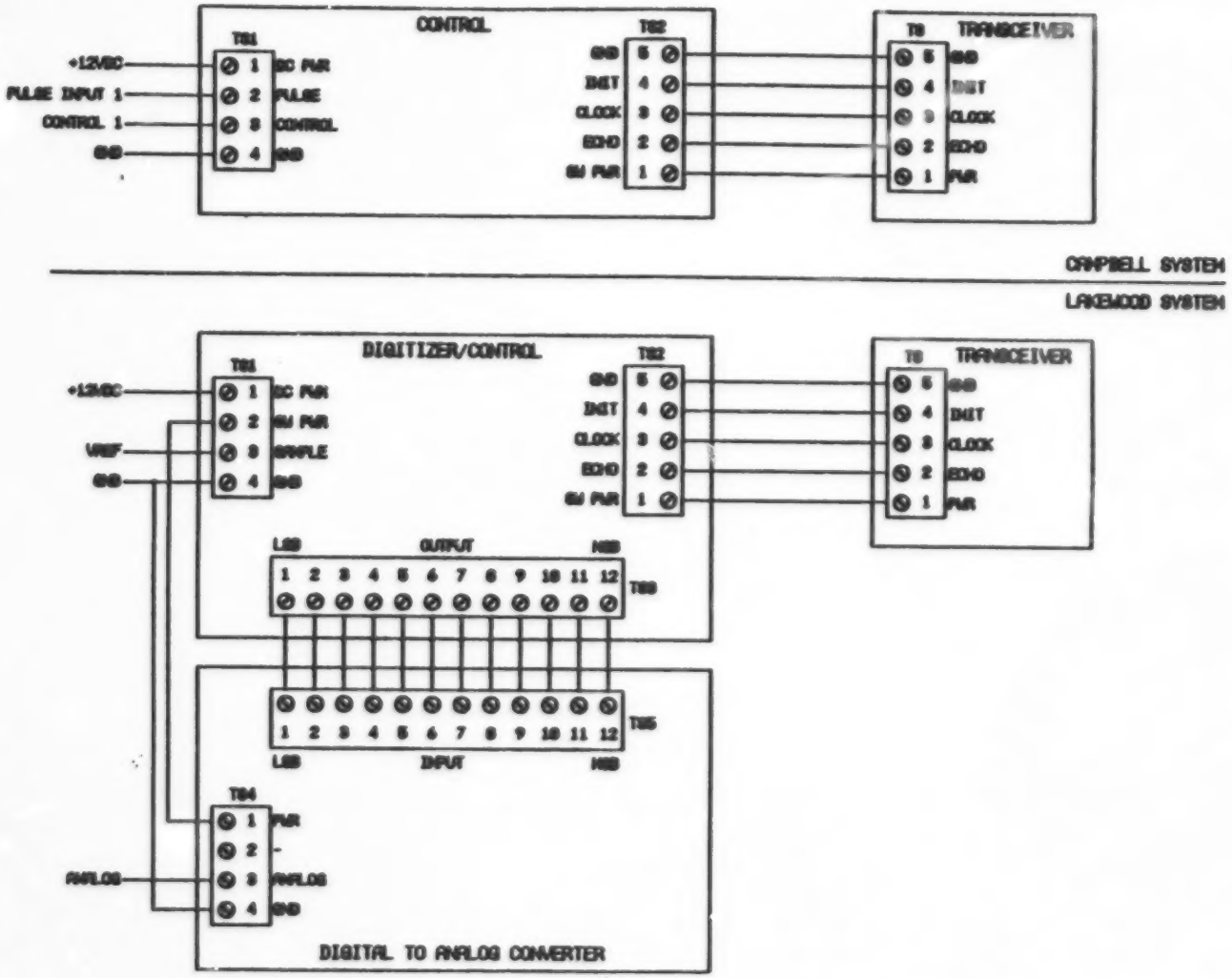


Figure 1 Schematic representation of the ARC sonar ranging system.

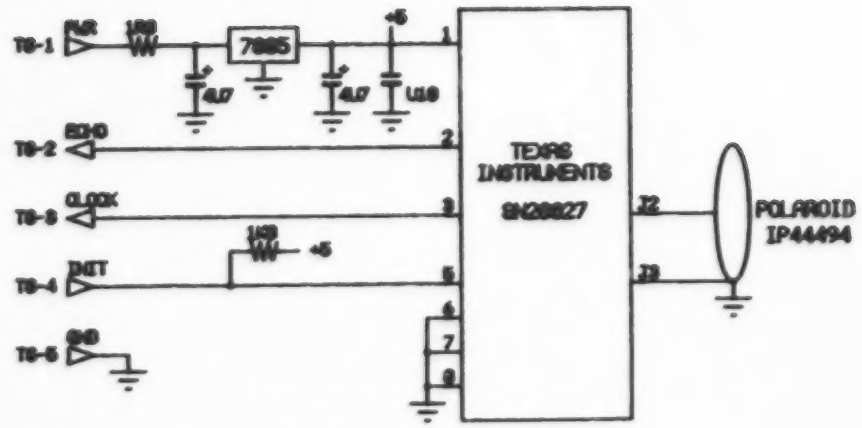
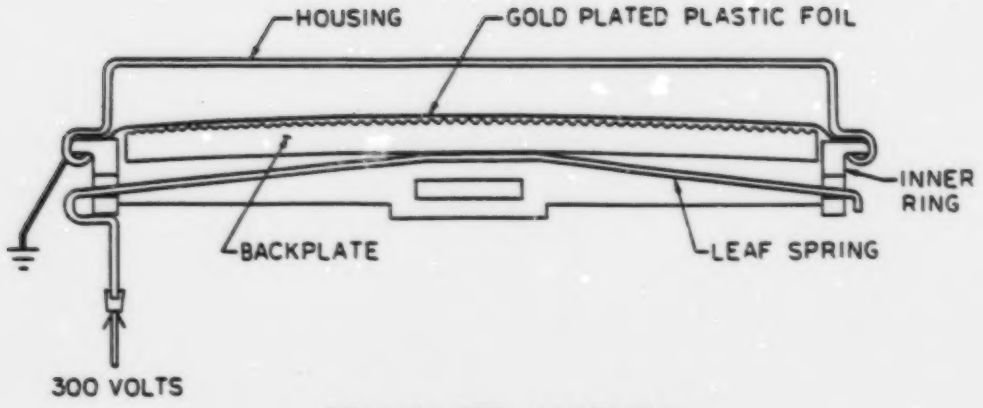


Figure 2 Schematic representation of the sonar tranceiver unit.



TRANSDUCER ASSEMBLY

FIGURE 1

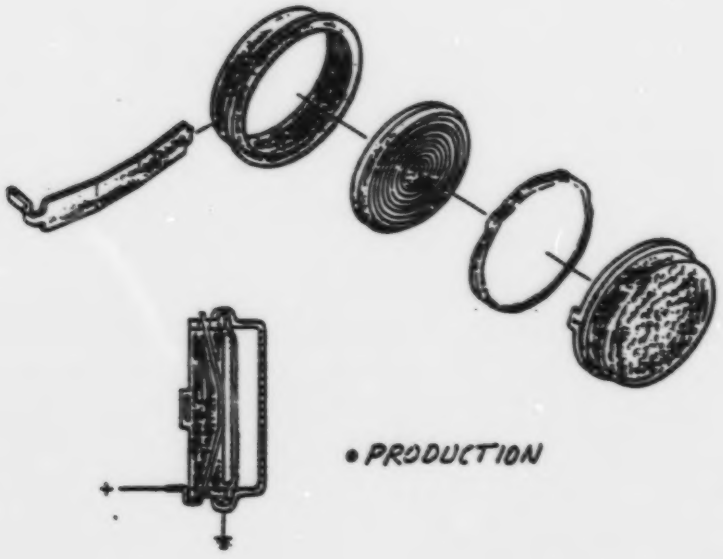


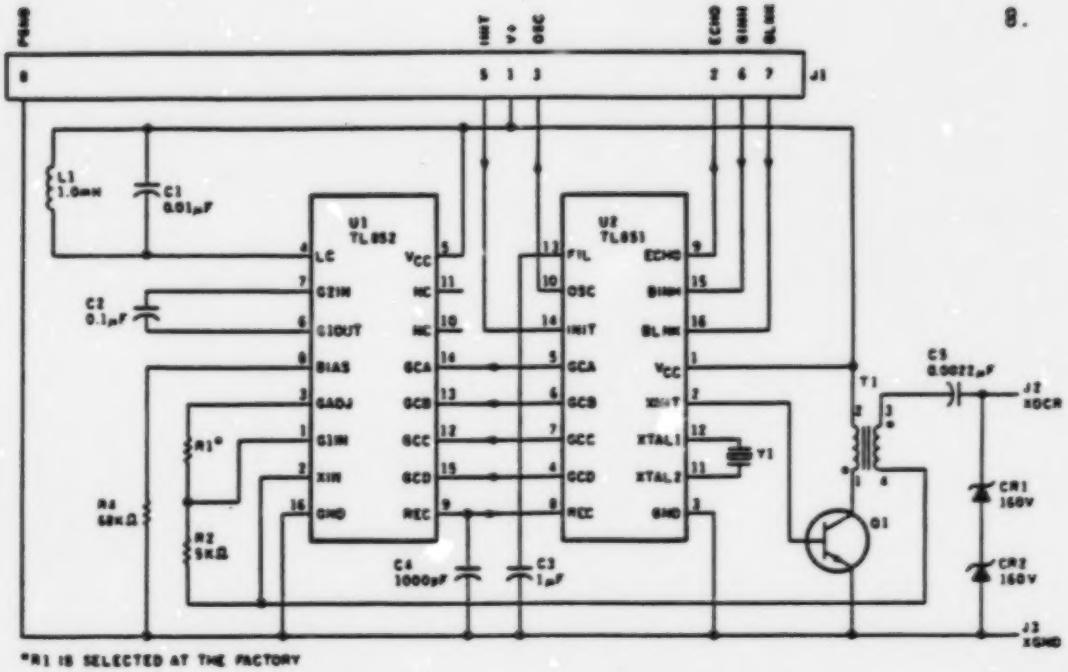
Figure 3 Transceiver assembly (after Biber et al., 1980).

externally to ensure that the foil is always displaced a sufficient amount to prevent it from collapsing against the backplate. The transducer acts as a loud speaker when it is activated by the AC power and emits soundwaves. These soundwaves reflect from the surface of the object being sensed and are picked up on their return when the sound disturbs the foil and generates an electrical pulse. The difference in time between when a pulse is emitted and when it is received is a measure of the distance between the film surface and the object. Characteristics and specifications of the environmental ultrasonic transducer are summarized in Appendix A.

The SRM, which drive the 50 kHz, 300 V EUT sensor is a two chip, 12 component custom-manufactured module, constructed around the Texas Instruments TL851 and TL852 sonar-ranging controller/receiver chips (figure 4). Its main function is to control the transceiver by alternating its function between sending and receiving.

One of two basic modes of operation can be chosen. A multiple echo mode can be used for sensing a number of objects at a variety of distances. However, interpreting the output and identifying all the correct distances becomes extremely difficult. In a single echo mode, where only one target exists, the data reduction is much simpler and in a majority of situations this mode of operation is all that is required. This mode is what is used and what will be addressed herein.

Figure 5 is a timing diagram which illustrates the way in which the SRM uses the EUT to measure distances. Within 5 ms of applying power the internal circuitry of the SRM is reset and stabilized and the module is ready to make a measurement. The distance-measuring sequence is activated by raising the INIT input line to a logic 1 state. This enables the 420 kHz on-board ceramic resonator, and 16 cycles of a 300 V 49.4 kHz signal are generated. The 16 cycles are passed through a driver/transformer combination that boosts the signal to 300 V at the transducer. At the end of the 16 cycles, a DC bias of 150 V remains on the transducer for optimum operation, and the oscillator output steps up to 93 kHz where it remains as long as INIT is high. The transmitted



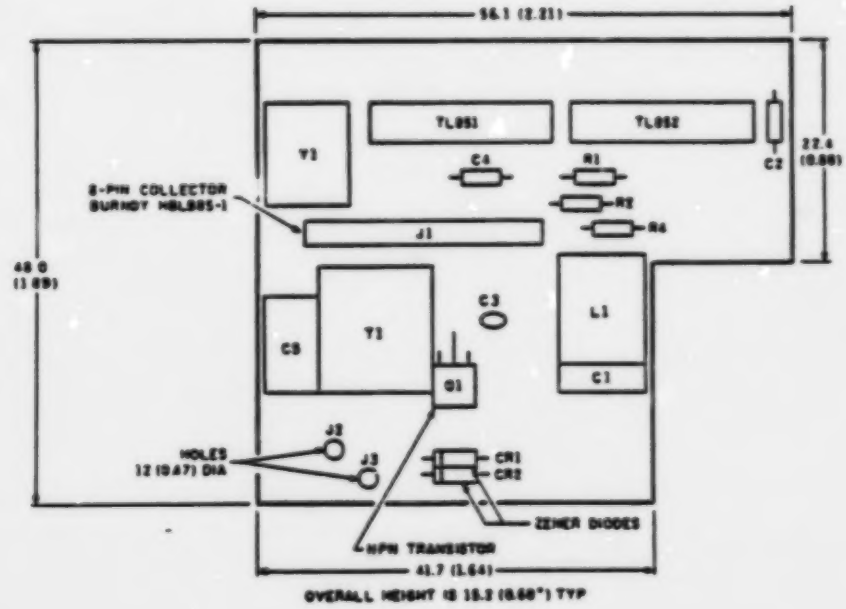


Figure 4 The layout and schematic representation of the Texas Instruments sonar ranging module (SRM).

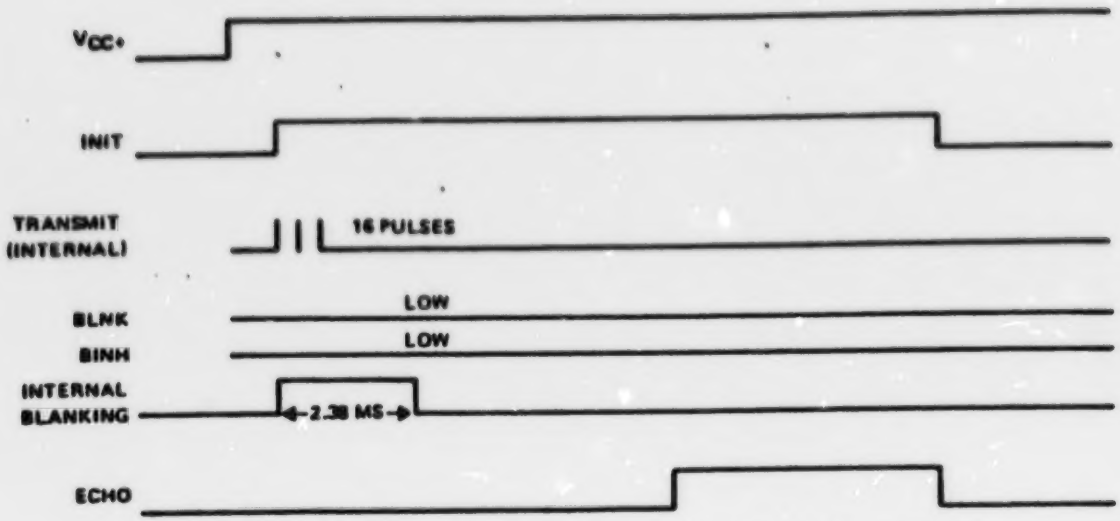


FIGURE 1—EXAMPLE OF A SINGLE-ECHO-MODE CYCLE WITHOUT BLANKING INPUT

Figure 5 An example of a single-echo-mode cycle without a blanking input.

pulse is emitted by the transducer and a portion of this energy is eventually reflected by an object. When the ranging module detect this echo, the ECHO output line goes high. The difference in time between INIT going high and ECHO going high is a measure of the distance to the target.

In order to prevent any resonance in the transducer from being detected as a return signal, the receive input of the ranging control integrated circuit is inhibited by an internal blanking signal for 2.38 ms. This blanking interval corresponds to 0.40 m, which is the minimum distance that the ranging module can sense without external control intervention.

Difficulties arising from the attenuation of the sound intensity are addressed by increasing the receiving amplifier's sensitivity by automatically adjusting its gain. For example, if a transmitter - and receiver - system works well at 2 meters it may not function well at 4 meters without substantially increasing the sensitivity of the receiver. Leaving the sensitivity at a high level and reducing the distance causes interface and false-echo-detection problems. Thus the variable gain feature is extremely important.

Twelve gain steps within the range of 0 to 15 m are automatically incremented as the time between INIT and ECHO lengthens. If the distance is 2 m, the receiver will be at its second gain setting. At 10 m it will be at its sixth level. The twelfth level is sufficient for unaided reception of echoes from 15 m. The addition of a sound-direction cone to the transducer can further improve sensitivity.

The elapsed time between when the INIT input goes high and the ECHO output line goes high indicating the echo has returned can be measured using an external time-base or the SRM oscillator output can be gated with the ECHO signal to increment a counter and drive a display. The time is determined from a clock which sends out pulses from the sonar control unit. In the units described herein, the pulses are counted by either the data logger or a special digitizing control unit.

It should be noted that the SRM requires between 4.5 V and 6.8 V of power for normal operation. This is not typical of a majority of power supplies. The 7805 voltage regulated (figure 2) was incorporated to enable the use of power supplies with voltages higher than the SRM upper limit, up to a maximum of 30 V.

For operation of the SRM unit within its normal voltage range, the 7805 regulator and the 1R0 current limit resistor can be bypassed and one of the 4U7 capacitors can be omitted.

2.2 Sonar Control Unit

2.2.1 Campbell Scientific 21 X Operation

The sonar control unit is the interface between the host Campbell data logger and the sonar transceiver unit. The control unit accepts a single logic signal from the data logger to perform a measurement and then return to a low power state when the logic signal is de-asserted. The control unit energizes the transceiver unit, waits for the SRM to settle, initiates a SRM transmit pulse, and gates the SRM clock pulses until an SRM echo signal.

An input signal from the data logger at TS1-3 (figure 6) causes power to the transceiver. The timer ensures that 10 ms elapses to allow the transceiver to settle after power-up. After that delay the INIT signal is asserted through TS2-4 prompting the transceiver to transmit a pulse and to starting the SRM clock. This clock is gated to the datalogger through TSI-2 until ECHO is received from the SRM through TS2-3. These pulses are counted by the 21 X and then converted to a distance using an appropriate expression for the speed of sound.

For the Campbell 21 X configuration, the whole system is powered by the 21 X internal battery of 8 alkaline D cells. When the sonar units are on standby, they draw approximately 100 μA. When powered up and idling they requires 100 mA, but during the transmit period 2 A is required. However, the overall duration of transmission is relatively

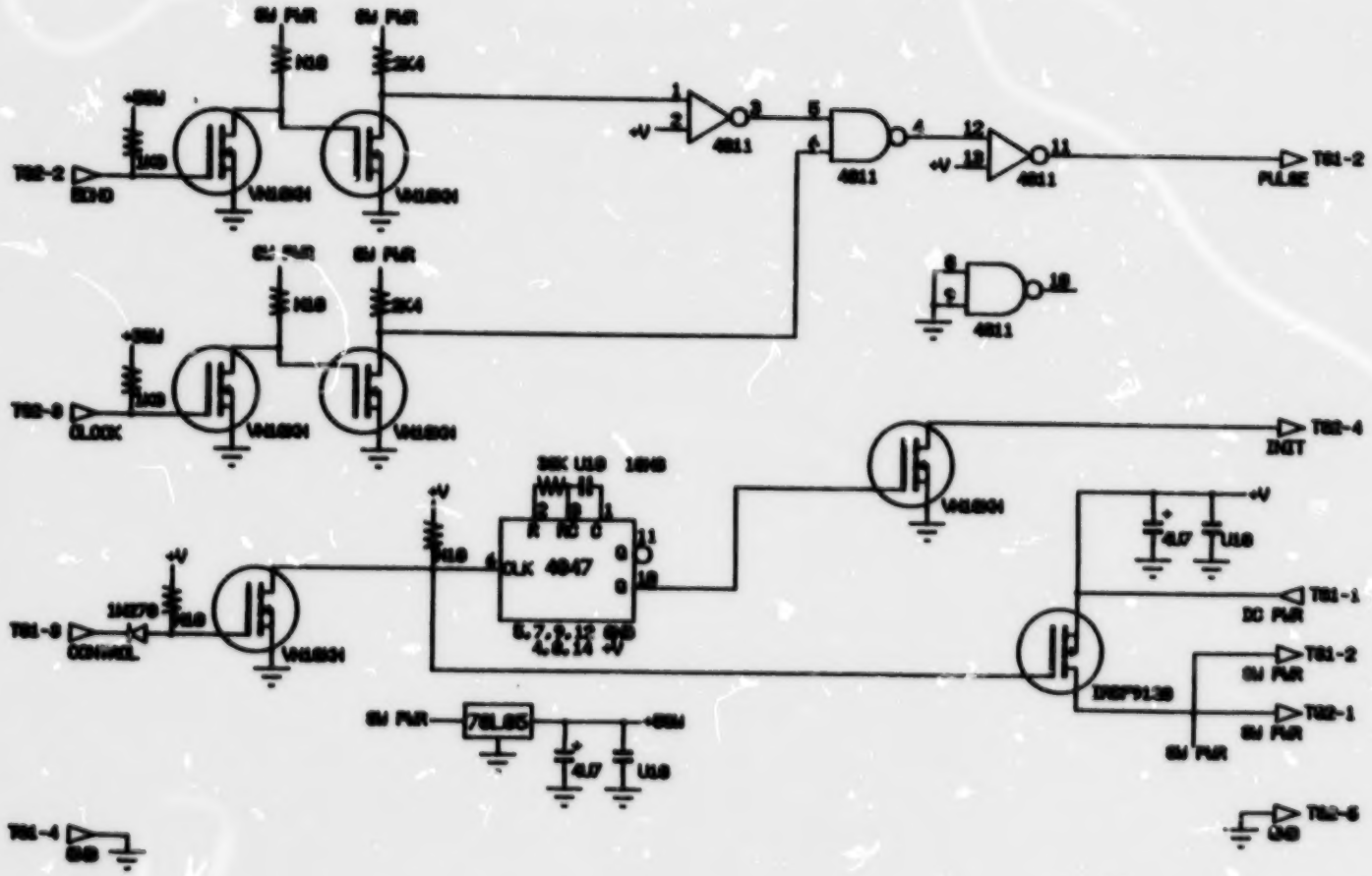


Figure 6 Schematic representation of the sonar ranging system control unit for Campbell Scientific 21 X applications.

small and therefore on the whole the unit consumes only a small amount of power.

2.2.2 Lakewood LE8100 Operation

The sonar control unit for this type of configuration is considerably more complicated than for the Campbell system because the Lakewood logger inputs are strictly analog. Thus a digitizing control unit and a digital to analog converter must be used.

The digitizer/control unit (figure 7) is activated when a reference voltage from the Lakewood logger is received at TS1-3. This signal triggers a timer to effect a delay allowing the transceiver time to settle after power-up. The INIT signal is asserted via TS2-4 causing the transceiver to transmit a pulse and the clock in the SRM to emit pulses. The clock pulses from the SRM enter the digitizer/control unit via TS2-3 and are routed to a binary counter until the ECHO signal from the SRM is received via TS2-2. This stops the counter and the number of pulses are held in binary form. It should be noted that the SRM clock pulses go through a 4013 flip-flop which divides the frequency of the clock signal. This increases the range of the binary counter from only 7.5 m to the full 15 m. However, this is achieved at a cost of reducing the resolution from 2 mm to 4 mm.

The binary code from the digitizer/control unit (TS3-1 to 12) enters the digital to analog converter (figure 8) via TS5-1 to 12 where it is converted to a voltage scaled from 0 to +2.5 and fed into one of the Lakewood LE8100 analog ports.

2.3 Temperature Compensation

For operation with a Campbell Scientific 21 X host data logger, instantaneous measurement of temperature compensated distance can be

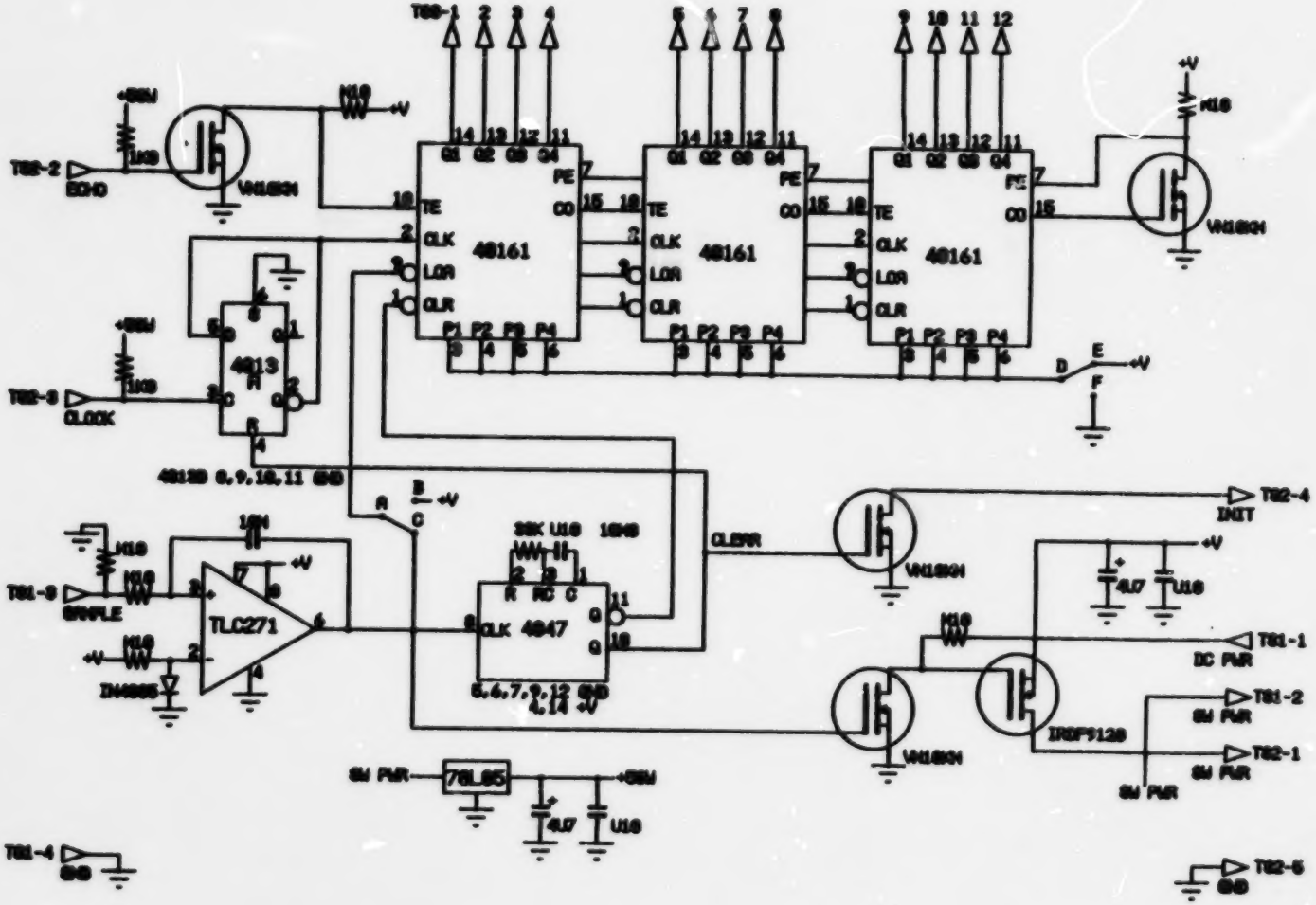


Figure 7 Schematic reprsentation of the sonar ranging system digitizer/control unit for Lakewood LE8110 applications.

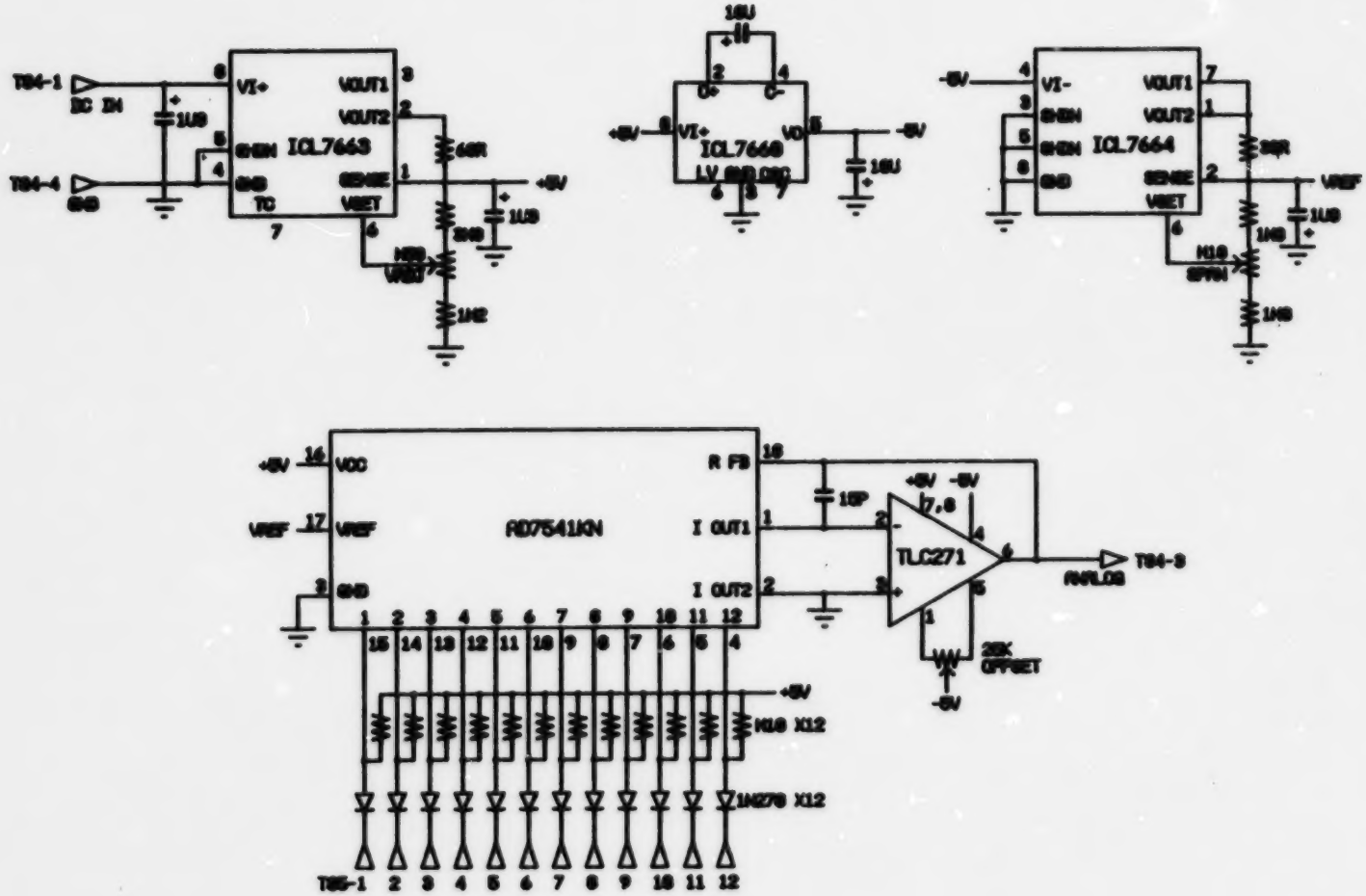


Figure 8 Schematic representation of the sonar ranging system digital to analog converter unit for Lakewood LE8110 application.

recorded. The Campbell 21 X executes a program which makes a temperature measurement by the attached thermocouple, prompts a sonar distance measurements, counts the control unit output pulses and then is capable of calculating distance. The distance is determined by:

[1] $DIST = [((PC/2) + 8)/93300] [330.7 + 0.607T_a]$

where DIST is the measured distance in metres, PC is the number of pulses (occurring at a rate of 93300 pulses/sec), and T_a is the air temperature in °C.

The first bracketed term on the right side of the equal side is the time conversion term. The pulse count is halved by the Campbell 21 X to prevent overflow problems in logged data storage. The +8 component is a correction of an artifact in the SRM clock output. This artifact is a reduction of 16 clock cycles when the unit is transmitting. This term has a precision of ± 1 clock cycle and is dependent on the accuracy specifications of the time base.

The second bracketed term is a linear approximation of the relationship between the velocity of sound and the air temperature. Over a temperature range of -40°C to +40°C this linear approximation is within ± 0.2% of actual values. It should be noted that the speed of sound varies only slightly (± 0.35%) over the whole range of expected humidity. The error introduced by not compensating for humidity is extremely small and therefore has been disregarded.

The Lakewood LE8110 data logger does not have the capabilities of the Campbell 21 X. It has no computing power on board and no nigh speed pulse counting capability . Instead, the LE8110 logs both the voltage coming from TS4-3 (figure 8) and, on another analog input, the voltage associated with the output of the temperature probe being used. Pulse count, PC is determined from:

[2] $PC = 4095\ V/Vref$

where V is the measured voltage, Vref is the digital to analog converter reference voltage (2.5 V) and 4905 is the number of pulses representative of the full scale voltage, the pulse count and the measured temperature can be inserted into equation 1 to compute the distance.

Calculation of distance can be performed on site (Campbell) or post-facts using data line format conversion programs and routine and spread sheet functions (Campbell and Lakewood).

The Campbell 21 X data logging system was incorporated in the prototype sonar ranging system. This was due to the simplicity of the required sonar control unit and the flexibility of the 21 X inputs and programming. The pulse counting capability of the Campbell unit permitted a direct evaluation of the Sonar Ranging Module. A digitizing control unit and the digital to analog converter required to support a Lakewood data logging system would have introduced early errors, complicating this evaluation.

It is expected that for redundant systems, Lakewood data loggers would be an appropriate choice, owing to their lower cost, given time for interface development and testing.

3.0 SYSTEM EVALUATION

The sonar ranging unit was field tested to determine its capabilities. It is difficult to test its performance absolutely because, over the long term, it can only be compared to water level estimates made from the WSC gauge. These latter estimates may be in error, given potential problems with variable clock speeds and the possibility of the orifice being moved or plugged by frazil ice.

Nevertheless, the WSC measurements are the current standard and if the sonar ranging system performs well relative to these, given the inherent accuracies of both systems, then there is potential for it use. It should be borne in mind, however, that the sonic sounder may outperform the WSC gauge and in fact be more representative of reality than the current standard adopted herein.

3.1 Installation

The ARC ultrasonic unit was field tested on the Low Level Bridge, on the North Saskatchewan River at Edmonton, at the same location as WSC gauge 05DF001. Installation was completed on November 20, 1987 and the evaluation of the unit continued from open water conditions through the development of the ice cover and well into the period of the stable ice cover. The evaluation was completed on February 2, 1988. During this period, the air temperature varied from a minimum of -26.2°C to a maximum of 6.7°C. The average temperature for the period was about -5°C but the coldest month was January, 1988, which had a mean temperature of -12.1°C.

The sonar control unit and the Campbell 21 X data logger (figure 9) were mounted in a steel box, approximately 200 mm x 260 mm in size. This box was mounted on the railing of the bridge (figure 10) so that the 21 X data logger could be easily accessed for interrogation. In this case a Radio Shack TRS 80 Model 100 portable computer was used to remove data from the Campbell logger.

Figure 9 Principle components of the sonar ranging system. The transceiver is connected to the control unit which inturn is connected to the Campbell 21 X data logger.

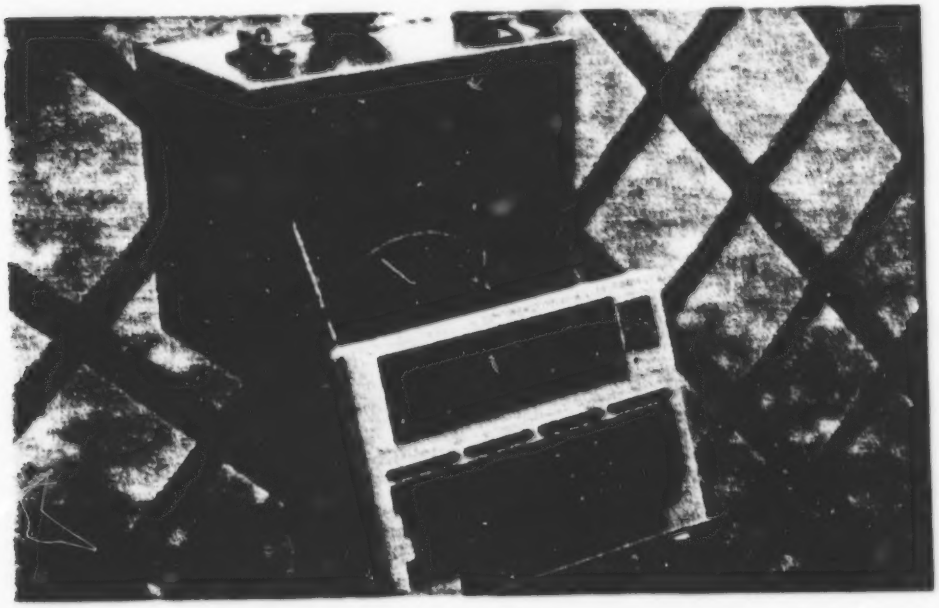


Figure 10 Housing for the Campbell 21 X data logger and sonar control unit, mounted on the Low Level Bridge. The Radio Shack portable computer used for interrogating the data logger.

A 1 m long 20 mm diameter conduit was used to rigidly suspend the sonar transceiver unit from the bridge. This conduit was shaped to conform to the bridge superstructure and also served as a housing for the cable connecting the transceiver to the sonar control unit (figure 11). The transceiver was housed in a 100 mm x 55 mm x 40 mm metal box attached to the end of the conduit (figure 12). This housing seem to adequately protect the transceiver unit from the elements. The equivalent gauge height of the transceiver was established to be 16.273 m.

Temperature measurements were made using a simple thermocouple connected directly to one of the Campbell 21 X logger analog inputs. The thermocouple wire was run through the conduit and suspended in the air in the vicinity of the transceiver box. Care was taken not to allow the thermocouple wire to position itself between the transceiver and the water surface and hence give faulty distance measurements.

It should be noted that for the entire test period readings were being taken at intervals of one minute. During this time, power was supplied by the original 8 alkaline D cell batteries used to power the Campbell logger. There was no significant reduction in the voltage to cause a deterioration in the performance of the sonar ranging unit.

3.2 Performance Characteristics

As described earlier the evaluation period extended from November 20, 1987 to February 2, 1988. During this period, the water levels were measured by the sonar ranging system at intervals of one minute. These measurements were averaged for each fifteen minute period by the Campbell logger and stored as a discrete pulse count which was representative of water level during that fifteen minute period.

For the purposes of evaluation, not all the data was analyzed. Instead a number of days were chosen more or less randomly, but with the intent of sampling a whole range of temperature conditions. In addition to this, the freeze-up period, December 27-31, was singled out as an

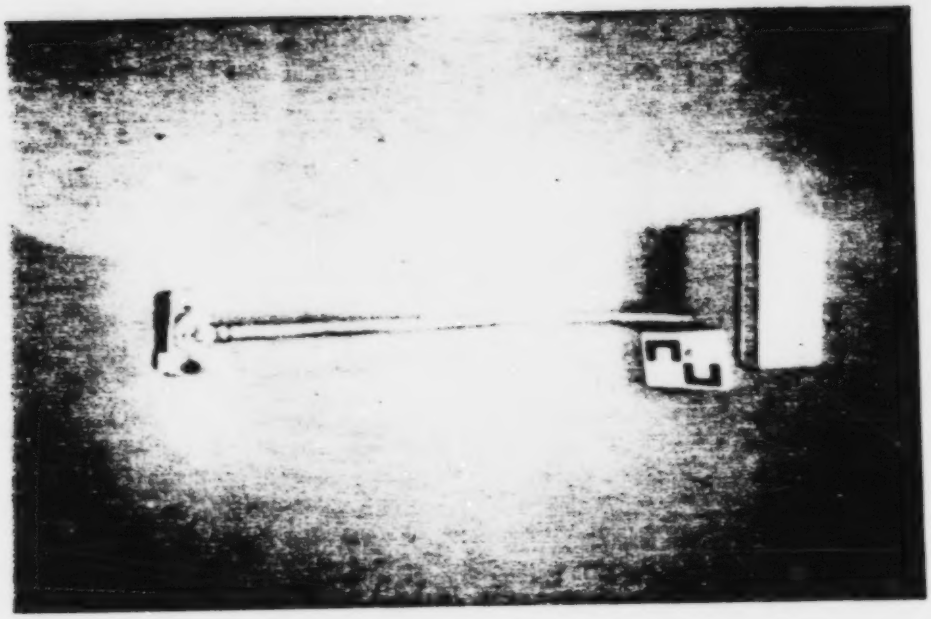


Figure 11 Assembly used to position the transceiver on the bridge.

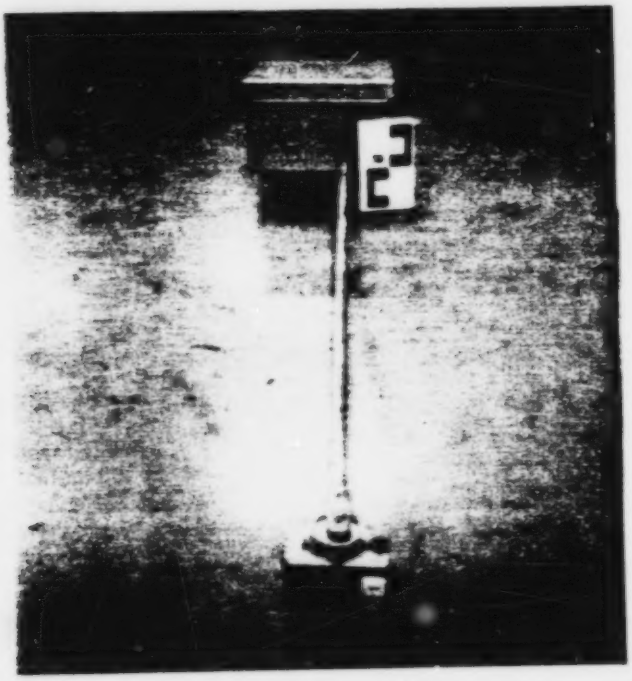


Figure 12 Housing for the transceiver unit.

important event and also included in the analysis. Table 1 summarizes the data used in the analysis and figure 13 illustrates the stage fluctuation during the freeze-up period.

3.2.1 WSC Accuracy

The WSC mountains continuous recording of river levels at this site. The record consists of an uncorrected strip chart similar to that shown in figure 13. For this particular location the vertical scale used in plotting the stage variation is 1 cm = 0.10 m or 1:10. From the strip chart is appears that for any one time, the best estimate of the stage can be made to within ± 0.002 m. Thus potential errors can as much as 0.004 m simply because of the clarity of the strip chart.

In addition to the errors arising from the poor resolution of the strip chart, certain systematic errors such as clock speed variability and perhaps movement of the orifice also contribute to the accuracy of the record. Attempts are made to compensate for these systematic errors by digitizing the strip chart and adjusting the data on an hourly basis, in some systematic fashion, between points of known stage for known times. This is similar to removing "drift" from a record.

Analysis of the data gathered within the verification period suggests that on a whole there is remarkably little difference between the uncorrected strip chart data and the corrected final official data. Under ideal conditions, when random errors are probably minimal, figure 14 suggests a scatter of about ± 0.035 m about the best fit linear regression line between the corrected and uncorrected data.

For less than ideal circumstances, such as when rapid fluctuations occur during ice cover formation or when reversals occur, there is substantially less reliability in both sets of data. For the example considered in figure 14, errors up to ± 0.16 m may occur in attempting to come up with some rational estimate of the water level.

Table 1 Summary of randomly selected water levels and air temperatures at the WSC gauge on the North Saskatchewan River at Edmonton, November 25, 1987 to January 7, 1988

Date	Hour	Water Level (m) WSC (uncorrected)	WSC (corrected)	Air Temp (°C)	Water Level (m) ARC (uncorrected)	ARC (corrected)	Corrected Difference (m) (ARC-WSC)
87-11-25	18:00:00	3.170	3.161	1.1	2.652	3.193	0.032
	20:00:00	3.060	3.087	-1.0	2.485	3.083	-0.004
87-11-26	00:00:00	2.900	2.905	-3.7	2.248	2.923	0.018
	06:00:00	2.755	2.752	-3.8	2.087	2.773	0.021
	12:00:00	3.040	3.040	3.5	2.505	2.993	-0.047
	18:00:00	3.060	3.045	2.0	2.540	3.063	0.018
87-11-27	00:00:00	2.885	2.876	0.3	2.328	2.903	0.027
	06:00:00	2.790	2.786	-3.1	2.136	2.803	0.017
	12:00:00	2.970	2.978	2.1	2.396	2.923	-0.055
	18:00:00	3.140	3.123	0.5	2.596	3.153	0.030
87-11-28	00:00:00	2.890	2.889	-2.9	2.257	2.913	0.024
	06:00:00	3.030	3.025	-4.4	2.357	3.043	0.018
	12:00:00	2.980	2.974	2.2	2.429	2.953	-0.021
	18:00:00	3.000	2.993	0.0	2.438	3.013	0.020
87-11-29	00:00:00	2.860	2.868	-2.8	2.238	2.893	0.025
	06:00:00	2.850	2.827	-4.4	2.165	2.863	0.036
	12:00:00	3.230	3.221	7.8	2.735	3.113	-0.108
	18:00:00	3.070	3.042	3.0	2.596	3.093	0.051
87-11-30	00:00:00	2.900	2.887	0.1	2.355	2.993	0.106
	06:00:00	2.780	2.764	-3.0	2.129	2.793	0.029
	12:00:00	2.745	2.745	2.6	2.117	2.643	-0.102
	18:00:00	2.995	2.979	-0.5	2.423	3.013	0.034
87-12-02	00:00:00	2.845	2.823	-3.5	2.189	2.863	0.040
	06:00:00	2.695	2.691	-2.6	2.055	2.713	0.022
	12:00:00	2.970	2.969	5.8	2.489	2.923	-0.046
	18:00:00	3.055	3.040	0.0	2.468	3.043	0.003
87-12-04	00:00:00	2.960	2.945	-0.4	2.384	2.973	0.028
	06:00:00	2.880	2.873	-2.4	2.238	2.883	0.010
	12:00:00	3.000	2.977	4.2	2.521	2.993	0.016
	18:00:00	3.355	3.340	2.9	2.885	3.373	0.033

Date	Hour	Water Level (m) WSC (uncorrected)	WSC (corrected)	Air Temp (°C)	Water Level (m) ARC (uncorrected)	ARC (corrected)	Corrected Difference (m) (ARC-WSC)
87-12-06	00:00:00	2.980	2.946	-0.7	2.378	2.973	0.027
	06:00:00	2.760	2.763	-0.4	2.155	2.753	-0.010
	12:00:00	3.020	2.987	2.8	2.466	2.973	-0.014
	18:00:00	3.550	3.523	1.4	3.066	3.583	0.060
87-12-14	00:00:00	3.195	3.189	-7.3	2.453	3.236	0.047
	06:00:00	3.100	3.101	-6.1	2.382	3.141	0.040
	12:00:00	3.040	3.034	-2.1	2.386	3.047	0.013
	18:00:00	3.195	3.181	-3.8	2.549	3.242	0.061
87-12-15	00:00:00	3.090	3.073	-7.5	2.382	3.175	0.102
	06:00:00	2.945	2.948	-6.0	2.260	3.021	0.073
	12:00:00	2.990	2.972	-3.3	2.312	3.006	0.034
	16:00:00	3.600	3.558	-1.9	2.913	3.544	-0.014
	18:00:00	3.640	3.668	-4.7	3.131	3.816	0.148
87-12-21	00:00:00	2.995	3.007	-6.1	2.319	3.080	0.073
	06:00:00	3.120	3.127	-0.6	2.560	3.177	0.050
	12:00:00	3.180	3.189	1.9	2.672	3.223	0.034
	13:30:00	3.175	3.188	3.3	2.697	3.215	0.027
87-12-27	00:00:00	3.035	3.053	-3.3	2.438	3.126	0.073
	06:00:00	2.960	2.978	-5.8	2.279	3.036	0.058
	12:00:00	3.105	3.127	1.7	2.564	3.124	-0.003
	18:00:00	3.295	3.304	-0.9	2.738	3.354	0.050
87-12-28	00:00:00	3.110	3.137	-6.3	2.431	3.191	0.054
	06:00:00	2.970	2.994	-8.3	2.212	3.034	0.040
	12:00:00	3.130	3.168	-3.7	2.416	3.112	-0.056
	18:00:00	3.800	3.768	-7.6	3.079	3.834	0.066
87-12-29	00:00:00	4.140	4.166	-8.4	3.687	4.425	0.259
	06:00:00	4.140	4.148	-6.9	3.821	4.517	0.369
	12:00:00	4.255	4.288	-9.7	3.951	4.701	0.413
	14:00:00	4.680	4.685	-10.1	3.932	4.692	0.007
	16:00:00	4.880	4.844	-10.2	4.484	5.213	0.369

Date	Hour	Water Level (m) WSC (uncorrected)	WSC (corrected)	Air Temp (°C)	Water Level (m) ARC (uncorrected)	ARC (corrected)	Corrected Difference (m) (ARC-WSC)
	18:00:00	4.830	4.772	-10.4	4.014	4.775	0.003
	20:00:00	5.045	5.004	-10.3	4.318	5.058	0.054
	22:00:00	5.200	5.113	-10.2	4.458	5.188	0.075
87-12-31	00:00:00	5.110	4.924	-16.7	4.147	5.034	0.110
	06:00:00	4.960	4.950	-12.0	4.277	5.056	0.106
	12:00:00	5.190	4.984	-10.8	4.299	5.051	0.067
	18:00:00	4.965	5.070	-12.2	4.392	5.167	0.097
88-01-02	00:00:00	4.870	4.868	-5.7	4.329	4.971	0.103
	06:00:00	4.805	4.802	-7.7	4.203	4.895	0.093
	12:00:00	4.965	4.948	-4.8	4.388	5.009	0.061
	18:00:00	5.035	5.032	-10.4	4.406	5.144	0.112
88-01-04	00:00:00	4.750	4.741	-22.6	3.806	4.847	0.106
	06:00:00	4.785	4.788	-24.3	3.806	4.855	0.067
	12:00:00	4.740	4.738	-17.8	3.854	4.787	0.049
	18:00:00	4.690	4.693	-16.9	3.887	4.798	0.105
88-01-07	00:00:00	4.640	4.648	-12.7	3.932	4.748	0.100
	06:00:00	4.690	4.690	-14.0	3.951	4.794	0.104
	10:30:00	4.635	4.647	-13.3	3.932	4.761	0.114

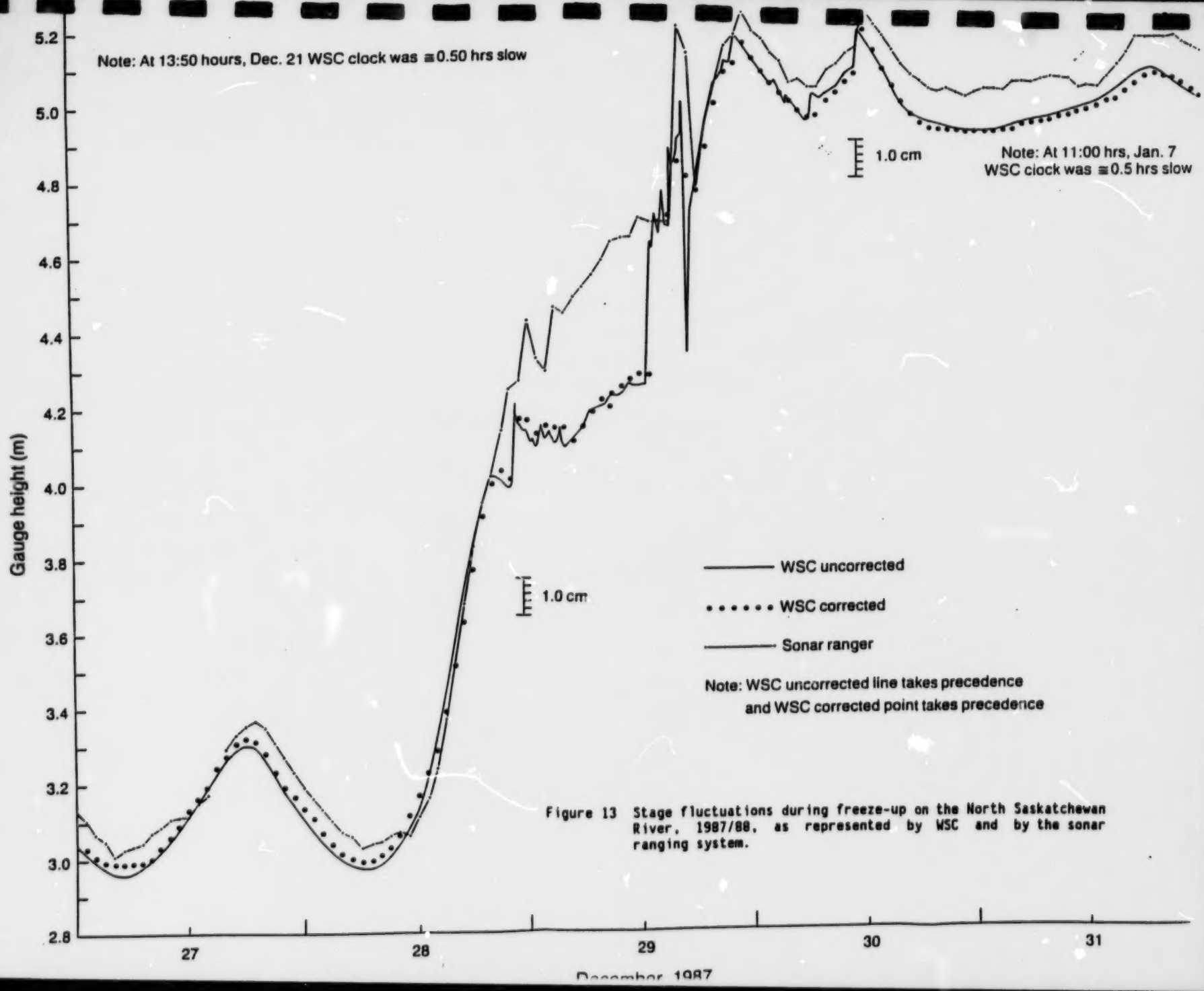


Figure 13 Stage fluctuations during freeze-up on the North Saskatchewan River, 1987/88, as represented by WSC and by the sonar ranging system.

It is difficult to determine what the accuracy of the WSC measurements are, because only a limited number of actual water levels are available over the period of this verification. It appears that it is possible to get errors or unexplainable differences in water levels of 0.01 m to 0.02 m when the strip chart becomes extremely complicated. This is also somewhat born out by figure 14.

3.2.2 Sonic Sounder Accuracy

Figure 15 illustrates the relationship between the sonic sounder measurement of the river stage and the WSC estimates of the river stage. This relationship is described by:

$$Yss = 1.0529\ Ywsc - 0.13728 \qquad (r^2 = 0.965)$$

where Yss is the gauge height from the sonic sounder and Ywsc is the gauge height from WSC. Assuming the WSC estimates are correct, the sonic sounder seemed to perform relatively well when the stage is less than 3.5 m. It over-predicts the stage only slightly and is always within ± 0.10 m of the WSC value. Once the stage exceeds 3.5 m it seems that the tendency to over-predict becomes more apparent.

During the formation of the cover, the relationship between the two methods is not well defined. Given the relatively good relationship for the open water conditions, and the possibility of inaccuracies in the WSC measurements during cover formation, it is probable that most of the poor definition arises out of errors in the WSC values. This is quite apparent in figure 13, where there even is a poor correlation between the raw WSC gauge heights and the corrected WSC gauge heights.

Following the establishment of a stable ice cover the relationship between the two techniques improves dramatically and is described by:

$$Yss = 0.98678\ Yws + 0.15683 \qquad (r^2 = 0.978)$$

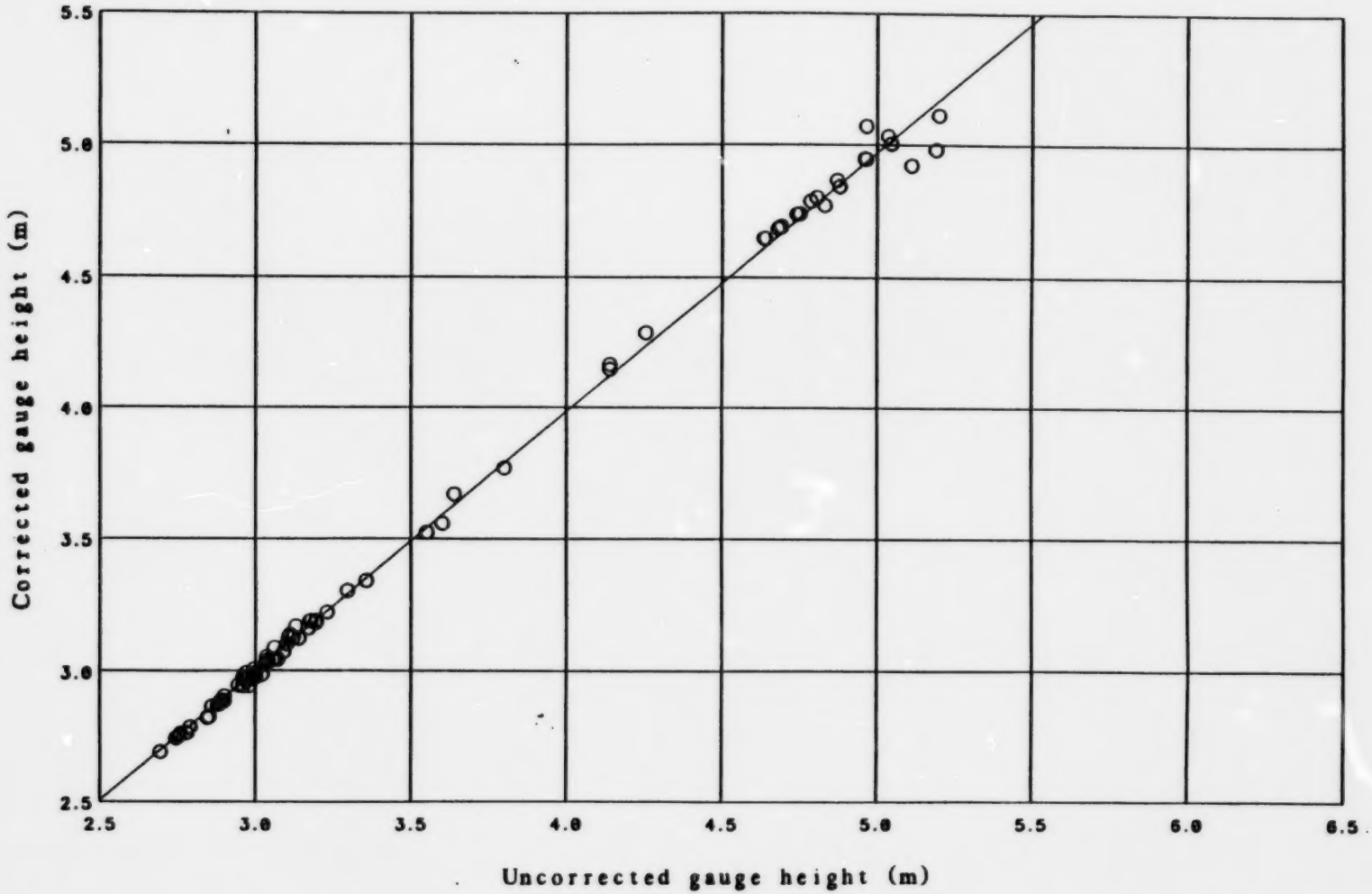


Figure 14 Comparison of uncorrected and corrected WSC gauge heights.

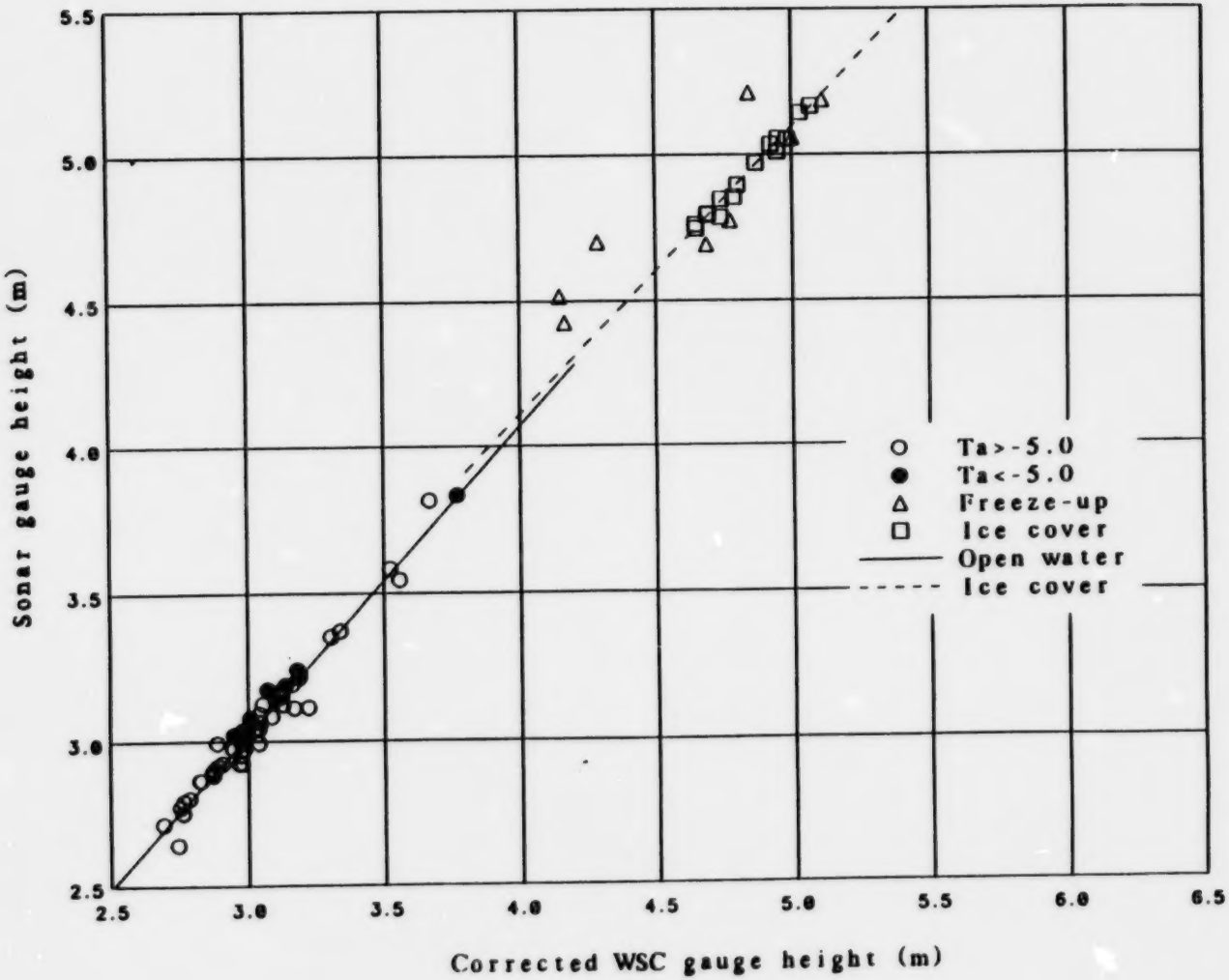


Figure 15 Comparison of the sonar ranging system gauge heights with the WSC gauge heights.

The slope of the line is very close to unity, suggesting that there are no differences as a function of the stage. However, there is a constant offset of about 0.10 m. This is equivalent to the unsubmerged thickness of the ice cover and can be explained by the fact that the WSC gauge measures the hydrostatic water level, which the sonic sounder measures the location of the top of the ice cover.

What is the interest also, is that the thickness of the error band in the data, for the stable ice cover situation, is only 0.04 m. This is considerably less than for open water. Figure 16 offers some explanation. While there is open water at the gauge site there will be a significant thermal gradient between the transceiver and the water surface. Because the temperature used in the temperature compensation calculation is measured well away from the water surface it will be underestimated for cold days. Hence the velocity will be underestimated and the stage will be overestimated. If on the other hand the air is warmer than the water, the temperature will be overestimated and the stage will be underestimated. In figure 16 it is apparent that for air temperatures greater than 0°C, the sonic sounder gives lower stages than WSC and when the air temperature is less than 0°C the sonic sounder gives higher stages that WSC. These temperature related errors are significant and probably explain about 50% of the observed errors.

If, on the other hand, an ice cover is present, the temperature of the ice cover approaches that of the air and there is a relatively small thermal gradient over the ice cover. Thus, the measured temperature is a good representation of the average temperature of the column of air below the sonic sounder and the temperature dependent errors should be relatively small. This is borne out in figure 16 where the data representing the ice cover conditions form a band parallel and almost exactly straddling the 0.10 m value. The 0.10 m offset is due to the floating ice cover, as has been discussed in a previous paragraph.

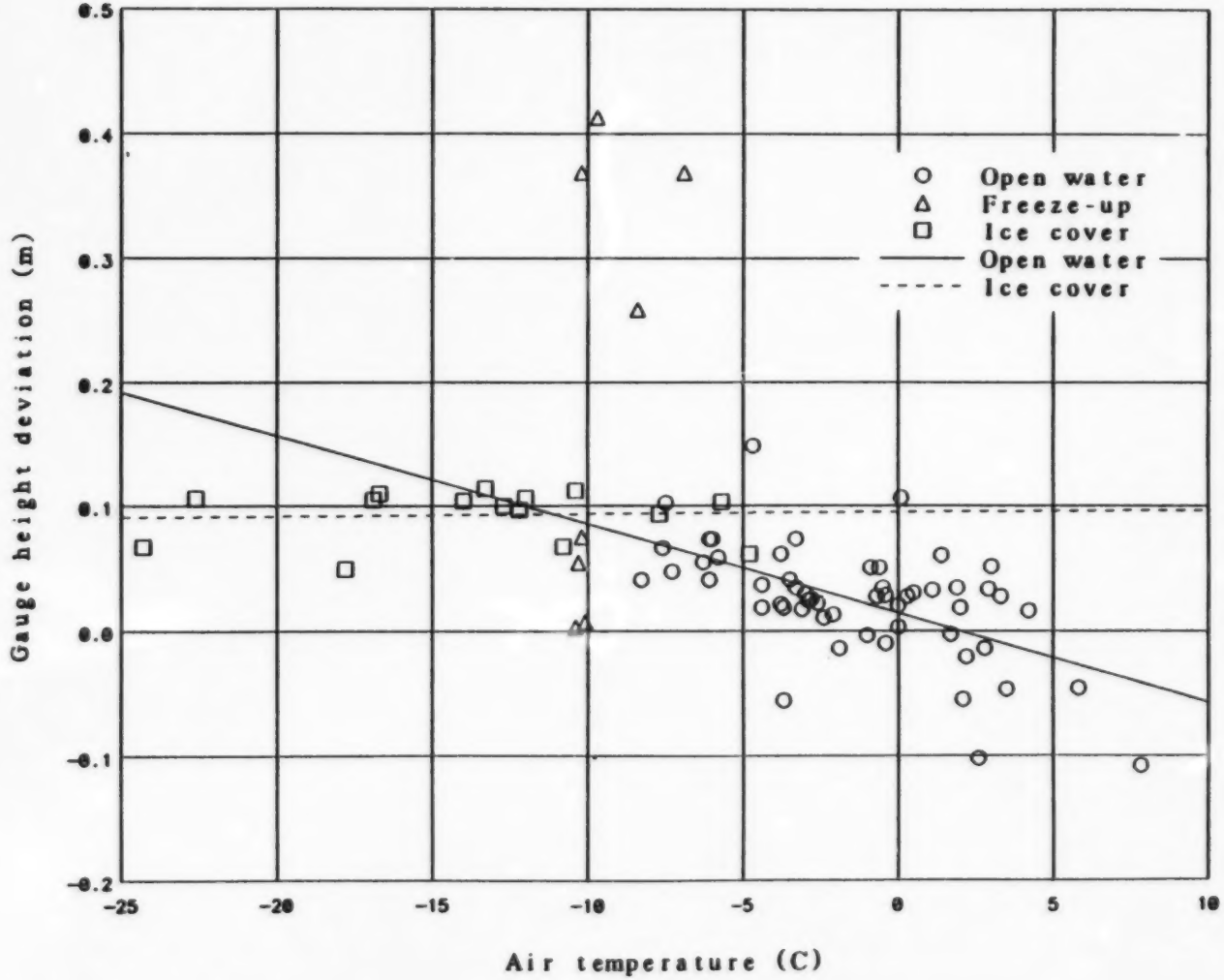


Figure 16 Effects of temperature on the accuracy of the sonar ranging system gauge heights.

4.0 SUMMARY AND CONCLUSIONS

This report describes a sonar ranging system, developed by the Alberta Research Council, which is suitable to measure water levels in large rivers. The system is composed of three main components which can be attached to any conventional data logger. The transceiver unit is the Polaroid Environmental Ultrasonic Transducer, connected to the Texas Instruments Sonar Ranging Module. These off-the-shelf devises are connected to the Sonar Control Unit which has been developed by ARC and is the main part of the system. Depending on what type of logger is being used (digital vs analog), the SCU can act simply as a connector to the data logger or it can function as a digitizer and an digital to analog converter.

Regardless of the type of data logger, the distance between the transceiver and the surface of the water can be measured to ± 4 mm if all the environmental compensations can be made. Unfortunately, air temperature significantly affects the speed of sound and it must be well represented, such that the appropriate temperature compensations can be made.

The systems ability to accurately measure river water levels was tested on the North Saskatchewan River at Edmonton, prior to and during freeze-up in late 1987 and into early 1988. The results indicate that this system has the potential to serve adequately as the primary method for water level measurements, especially under sever conditions when the WSC system cannot and does not perform up to standard.

Measurements indicate that under normal conditions the sonar system tracked very closely to the WSC system. Overall, under ideal circumstances sonar measurement was within ± 0.10 m of the WSC measurement. Obvious discrepancies seemed to be related to variation in clock speeds, which suggests that the WSC measurements may have been incorrect, given the WSC propensity for inaccurate clocks.

Under more severe conditions, when rapid stage fluctuations and chart reversals were common, there was a wide discrepancy between the two systems. Again, it seems that the WSC measurements were less reliable, given the subjectivity of interpreting both the reversals and the sharp peaks on the strip chart.

The main draw back with the sonar system is the need to adequately characterize the temperature of the air between the transceiver and the water surface. The measurements indicate that temperature gradients play a major role in reducing the accuracy of the sonar measurements. It is necessary to suspend one temperature probe at a representative height above water such that the average temperature of the column of air can be determined. Experience may, in fact, suggest that two probes may be necessary to adequately characterize the air temperature.

Nevertheless, once the air temperature problem is resolved the sonar system should prove to be available tool in measuring river stages. It can be used under normal conditions for routine stage measurements and for special conditions when it is difficult to deploy existing technology due to the high costs and/or the high risks of failure.

5.0 BIBLIOGRAPHY

Biber, C. Ellin, S., Shenk, E, and Stempech, J. (1980) The Polaroid Ultrasonic Ranging System. Presented at the 67th Convention of the Audio Engineering Society, New York, New York., 32 pg.

APPENDIX A

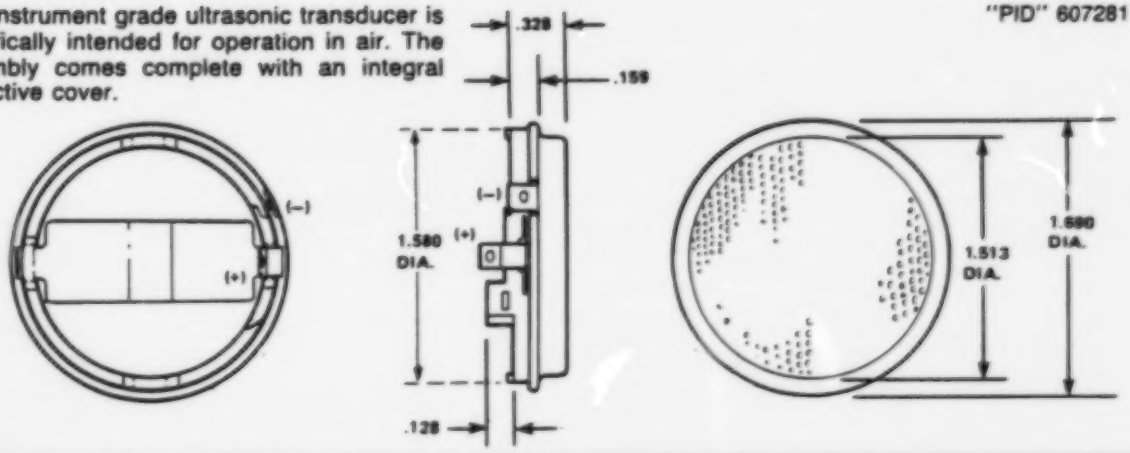
SPECIFICATIONS FOR THE POLAROID ENVIRONMENTAL ULTRASONIC TRANSDUCER

ENVIRONMENTAL ULTRASONIC TRANSDUCER

Polaroid

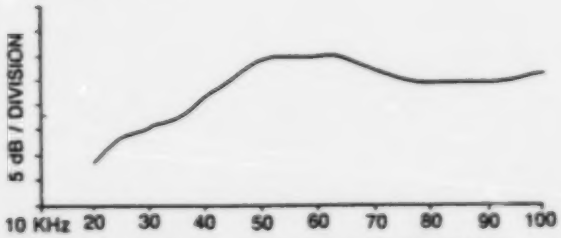
"PID" 607281

This instrument grade ultrasonic transducer is specifically intended for operation in air. The assembly comes complete with an integral protective cover.



ELECTRO-ACOUSTIC CHARACTERISTICS

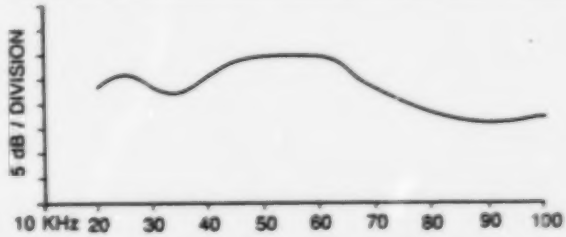
Type	Electrostatic
Usable Transmitting Frequency Range	See Graph 1
Usable Receiving Frequency Range	See Graph 2
Beam Pattern	See Graph 3
Minimum Transmitting Sensitivity at 50kHz 300 VAC pk-pk, 150 VDC bias (dB re 20 uPa at 1 meter)	110dB
Minimum Receiving Sensitivity at 50 kHz 150 VDC bias (dB re 1v/Pa)	–42 dB
Suggested DC Bias Voltage	150V
Suggested AC Driving Voltage (peak)	150V
Maximum Combined Voltage	400V
Capacitance at 1 kHz (typical) 150 VDC bias	400pf



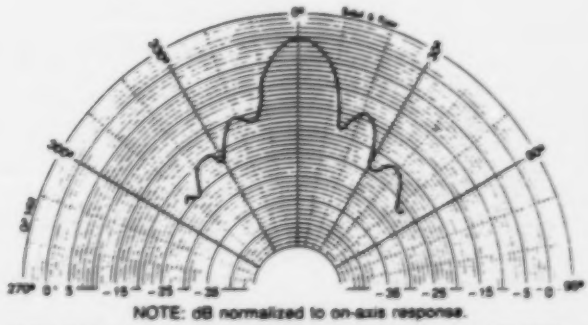
GRAPH 1. TYPICAL TRANSMIT RESPONSE

MECHANICAL CHARACTERISTICS

Construction	
Diaphragm	24K gold on Kapton Film
Housing	Stainless Steel



GRAPH 2. TYPICAL FREE FIELD RECEIVE RESPONSE



GRAPH 3. TYPICAL BEAM PATTERN AT 50 KHz

ENVIRONMENTAL CHARACTERISTICS — OPERATIONAL

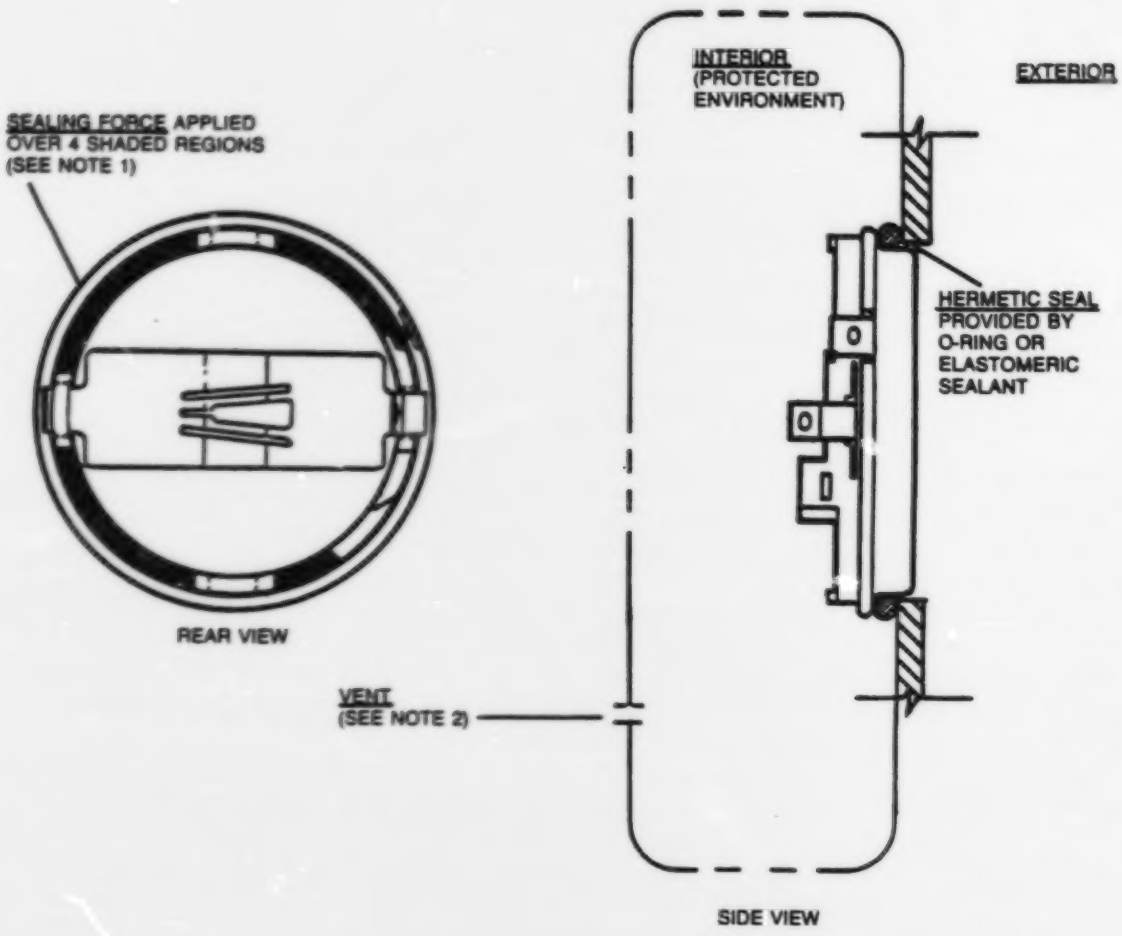
Temperature Range	–20°F to 160°F (–30°C to 70°C)

Combined transmit and receive sensitivity variation is less then 6 dB over this range.

Relative Humidity	5% to 95% non-condensing

ENVIRONMENTAL ULTRASONIC TRANSDUCER MOUNTING SUGGESTIONS

The following guidelines should be used when designing your own housing for the Polaroid Environmental Ultrasonic Transducer.


SEALING FORCE APPLIED OVER 4 SHADED REGIONS (SEE NOTE 1)
REAR VIEW
INTERIOR (PROTECTED ENVIRONMENT)
EXTERIOR
HERMETIC SEAL PROVIDED BY O-RING OR ELASTOMERIC SEALANT
VENT (SEE NOTE 2)
SIDE VIEW

NOTE 1

A uniform force must be applied on the plastic ring shown if an O-ring is used as a seal. The use of an elastomeric sealant such as RTV silicone rubber eliminates the need for a seal clamping mechanism.

NOTE 2

Provisions must be made to provide for equalization of air pressure between the front and rear of the transducer. The location and design of this vent must be such that water, dust, corrosives, or foreign matter are prevented from reaching the transducer's interior surfaces.

ENVIRONMENTAL CHARACTERISTICS — EXPOSURE

NOTE: The following tests were performed with the transducer housed in the ***POLAROID TEST ENCLOSURE (see FIGURE 1).*** *The* ***TEST ENCLOSURE*** *protects the sides and back of the transducer from exposure to any foreign matter. The rear of the transducer is vented to atmospheric pressure. Output and sensitivity of the transducer are reduced slightly when used in this enclosure.*

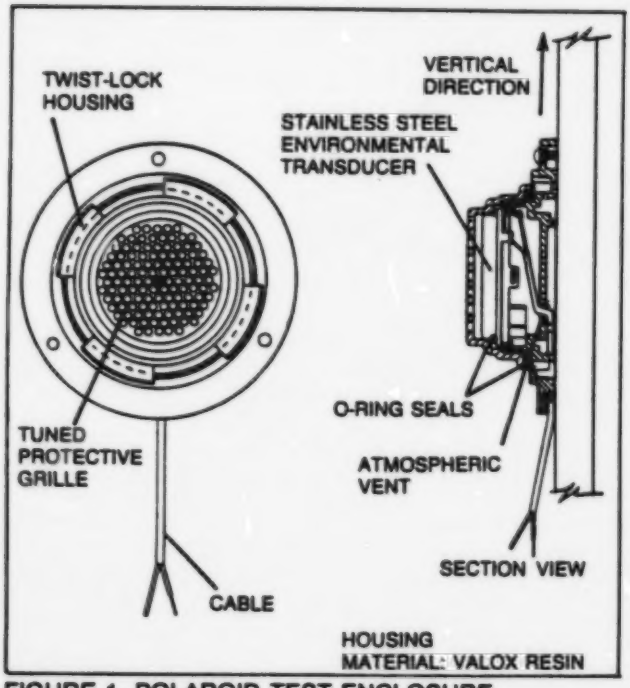


FIGURE 1. POLAROID TEST ENCLOSURE

After each test, transducers were cleaned and dried if necessary. Measurements were then taken at room temperature.

Variation in combined transmit/receive sensitivity at 50kHz was no more than 4.5 dB after any one of the following tests.

Storage Temperature Range −40°F to 250°F (−40°C to 120°C)

Salt Spray Exposure
5% salt spray solution at 95°F (35°C) 96 hours

Shock and Vibration
50 G peak in each direction along 3 perpendicular axes, pulse duration: 6.5 ms;
6 G's RMS 20 - 2000 Hz for 6 minutes

Water Immersion (vent hole sealed) 24 hours

Freeze/Thaw Cycle 4 cycles
Spray with water, drain, expose to −20°F (−30°C) for 20 minutes, allow to warm to room temperature.

Chemical Exposure
Gasoline, acetone, sulphur dioxide. Samples sprayed with/exposed to chemical then placed in 120°F (49°C)/90% relative humidity environment for 24 hours.

Sand Bombardment 20 cycles
50ml fine sand poured from 4 feet onto front grill

No claim for performance is made without an enclosure providing protection equal to or better than that provided by the **POLAROID TEST ENCLOSURE.** Similarly, no claim is made for performance in any other environments or under any other conditions than those described herein.

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

WARRANTY: We will, within 90 days from date of shipment, replace or, at our option, repair any products or parts thereof sold hereunder which are found to be defective in material or workmanship. Our obligation with respect to such products or parts shall be limited to replacement or repair f.o.b. Cambridge, Mass. and in no event shall we be liable for consequential or special damages, or for transportation, installation, adjustment, or other expenses which may arise in connection with such products or parts. No waiver, alteration or modification of this paragraph shall be valid unless made in writing and signed by an executive officer of Polaroid.

For technical assistance call
Polaroid's Applications Engineers at 617-577-4681.